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Studies on the Physicochemical Properties of the Tubers of New Sweet Potato Lines[1]

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Abstract : This study was conducted with 17 new sweet potato lines and one commercial variety to investigate the physical and chemical properties of the tuber powder and to find out the relationship between tuber dry matter content, reducing sugar, starch content and enzyme activity of tuber amylase.

The starch granular size of these sweet potatoes ranged from 8.05×7.25μ to 28.98×26.57μ. The viscosity of the tuber powder solution at 90°C was about 20 times as large as that at room temperature. After cooling from 90°C to room temperature the viscosity was much higher than that at 90°C. The average dry matter content of these new lines amounted to 36.6 %, being much higher than that of Tainung 57(27.8 %). Three new lines had a dry matter content more than 40%. The tuber moisture content ranged from 56.5 to 72.2%, Tainung 57 had the highest moisture content, being 8.3 % higher than the average.

The tuber starch content on dry basis ranged from 61.99 to 75.38 %. More than half of the new lines had a higher tuber starch content than the average (67.93 %). The tuber starch content on wet basis ranged from 18.42 to 30.68 %. The commercial variety, Tainung 57, had the lowest tuber starch content on wet basis due to its low tuber dry matter content, while C 71-96 had the highest tuber starch content both on dry and wet basis. The average reducing sugar content was 3.71 %. C71-196 had the highest value of 8.44%, while C66-33 had only 0.24 %. The amount of the reducing sugar in tuber indicated that amylase more or less existed in the tuber. This enzyme can convert starch molecule into reducing sugar under normal pressure and temperature.

High significant relationships were found between these physicochemical properties, namely, tuber dry matter content and tuber starch content on wet basis ($r=0.97$), tuber starch content on wet basis and tuber starch content on dry basis ($r=0.77$) and reducing suger content and amylase activity ($r=0.98$). Because of the close relationship between tuber dry matter and tuber starch content on wet basis, the tuber dry matter percentage could be used to evaluate the tuber starch content on wet basis. A regression equation $\hat{Y}=0.82664\ X-5.25795$ was then derived, where $\hat{Y}$ was the tuber starch content on wet basis and X was the tuber dry matter.

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Introduction

Starch has a wide application possibility in many industries such as food and sugar industry. In the past years the oil crisis made it a valuable substitute energy resource. Because of insufficient storage of crude oil in the world, the importance of starch as a material to produce ethanol will distinctly increase in the future.

Except rice, sweet potato is a main starch resource in Taiwan, it can be grown three or four times a year with high yield and the tuber roots are rich in starch. Many factors affect the starch content of sweet potato, such as variety difference[7], location and year effects[7], and soil and fertilizer factors[1,2,3,4,5,13]. The autumn crop produces much higher tuber starch content than spring and summer crops do[7]. Long storage as well as early harvest generally decrease the starch content[12,14].

The quality of the sweet potato starch depends on the flavour, the colour, the viscosity and the component of the tuber[6]. Good tuber starch has good flavour, high viscosity and high starch content. The present study was to evaluate the starch quality of the new sweet potato breeding lines by determining their powder physicochemical properties.

Materials and methods

1. Material

A total of 17 breeding lines along with a variety were included in this study(Table1). They were grown in autumn of 1983 in three locations with growth period ranging from five months to six months. The experiment design in each location was 6 replications RCBD, with plot size of two rows of 8 m long. Pooled samples of middle sized tubers were used for all tests.

2. Methods: Each of the following determinations was made at least 4 times.

Granular size of tuber starch was observed with an Olympus microscope at 400 X power and the granular length and width were described.

One hundred ml of 9% tuber powder solution were taken to determine the viscosity value from room temperature (25°C) to 90°C with the Brookfield LVT viscosimeter.

One thousand g of root tuber pieces were heated in oven at 70°C for 24 hours to determine the dry matter and moisture content of the tuber.

Dry tuber powder was hydrolysed with acid-catalyzed method (25% HCl) and then neutralized with NaOH solution. After dilution, 5 ml of the diluted starch solution were taken to detect the sugar content with the Somogyi reagents. From the sugar content of each powder solution the starch content on dry basis can be calculated.

To determine the precise moisture content of dry tuber powder, two grams of powder were heated at 105°C under normal pressure until the constant weight was reached.

To determine the reducing sugar content of dry powder dry tuber powder of 0.5g was first diluted to 100ml. After stirring for one hour, 5ml of the diluted solution were taken to detect the reducing sugar content with the Somogyi method.

The starch content of each line or variety on dry weight basis was multiplied by its dry matter content to get the tuber starch content on wet weight basis.

The amylose content of each tuber powder was determined with the automatic industrial amylose determination method of Lachat chemicals, INC. This method is based on the reaction of iodine with amylose to form a complex which exhibits a blue colour and can be read at 620 nm.

Determination of the enzyme activity of starch amylase under standard condition: One ml of 0.5% tuber powder solution was mixed with 9ml of 0.56% standard starch solution (from Sigma, pH 5) and put on a waterbath of 40°C for 30 minutes. The reducing sugar content produced was determined with the Somogyi method. From this value the enzyme activity can be calculated with the following formula: Enzyme activity=0.1 x mg of glucose produced x dilution factor.

Table 1. Location and cultivation period of 17 sweet potato lines and one variety

Lines & variety	Location[a]	Cultivation period (Month)
C 64- 4	CAES	5.5
C 64- 42	YCD	5.0
C 65-356	CAES	5.5
C 66- 33	YCD	5.0
C 66- 41	YCD	5.0
C 66- 73	YCD	5.0
C 70-111	SYD	6.0
C 70-141	SYD	6.0
C 70-220	SYD	6.0
C 70-245	SYD	6.0
C 70-295	SYD	6.0
C 71- 92	CAES	5.5
C 71- 94	CAES	5.5
C 71- 96	CAES	5.5
C 71-157	CAES	5.5
C 71-171	CAES	5.5
C 71-196	CAES	5.5
Tainung 57	YCD	5.0

[a] C. A. E. S. : Chiayi Agricultural Experiment Station, TARI ; Y. C. D. : Yuen Chang District ; S. Y. D. : Shui Yen Di.

Results and Discussion

The tuber starch granules existed in single grains surrounded by a protein membrane which could be destroyed by heating. Under microsscopic observation the starch granules showed three distinct different sizes. The average size for the large granules was 25.38×23.74 μ, for the middle ones 17.03×15.16 μ and for the small ones 10.32×9.38 μ. Line C 71-157 had the largest granule (33.81×33.01 μ) and the largest middle granule (19.32×17.71 μ). Line C 70-111 had the largest small granule (12.88×11.27 μ). Line C 71-92 had the smallest granules in general (Table 2).

Table 2. Granular size of tuber starch

Lines & Variety	Range of large granular (μ)	Range of middle granular (μ)	Range of small granular (μ)
C 64- 4	24.15×23.35	16.10×14.49	9.98× 8.86
C 64- 42	28.98×25.76	17.71×16.10	10.47× 9.98
C6 5-356	24.15×23.55	16.10×14.49	8.05× 7.73
C 66- 33	27.37×24.15	18.52×17.71	9.66× 8.86
C 66- 41	24.47×24.15	17.71×16.91	9.66× 8.05
C 66- 73	28.18×24.96	18.52×15.30	11.27×10.47
C 70-111	24.96×24.15	17.71×16.91	12.88×11.27
C 70-141	24.96×24.15	17.71×16.10	12.08×11.27
C 70-220	27.37×25.76	18.52×17.71	8.86× 8.05
C 70-245	21.74×19.32	14.81×14.49	10.47× 9.66
C 70-295	22.54×20.93	16.42×16.10	11.27×10.47
C 71- 92	20.93×20.80	14.49×13.69	8.05× 7.25
C 71- 94	23.35×20.13	17.71× 9.66	11.27× 9.66
C 71- 96	22.54×21.74	16.10×15.30	11.27×10.47
C 71-157	33.81×33.01	19.32×17.71	11.27× 9.66
C 71-171	20.93×19.32	15.30×11.27	8.37× 8.05
C 71-196	27.37×25.76	17.71×14.49	11.27×10.95
Tainung 57	28.98×26.57	16.10×14.49	9.66× 8.05
Average	25.38×23.74	17.03×15.16	10.32× 9.38

The viscosity of tuber powder solution was largely affected by temperature. The average powder viscosity at different temperatures was 2.25 at initial room temperature, 2.00 at 40°C, 3.05 at 60°C, 44.77 at 90°C and 61.55 at final room temperature. The value at 90°C reached highest (100 centipoises) in 4 lines such as C 64-42 and nearly 100 centipoises in two lines such as C 66-41. After cooling the temperature of the solution from 90°C to room temperature the viscosity largely increased, except in four

lines such as C 70-111. The viscosity value of Tainung 57 was 44 centipoise at 90°C, more than 20 times of that at initial temperature, and reached the highest value after cooling to final room temperature (Table 3).

Table 3. Viscosity of 9 % tuber powder solution in sweet potatoes at different temperatures

Lines & Variety	Viscosity (Centipoise)				
	25°C	40°C	60°C	90°C	25°C[a]
C 64— 4	2.13	1.95	2.00	23.75	100.00
C 64— 42	2.53	2.55	1.88	100.00	100.00
C 65—356	1.98	1.77	2.58	64.65	100.00
C 66— 33	4.85	3.83	3.88	100.00	100.00
C 66— 41	1.95	1.65	1.88	97.70	100.00
C 66— 73	2.10	2.43	1.83	5.93	80.75
C 70—111	1.98	1.58	4.03	10.03	5.75
C 70—141	1.95	1.63	5.40	4.33	7.80
C 70—220	2.60	2.05	9.28	31.68	32.38
C 70—245	1.50	1.65	3.10	9.65	32.73
C 70—295	2.00	1.83	2.43	100.00	100.00
C 71— 92	2.18	2.08	1.90	4.80	27.08
C 71— 94	1.98	1.33	2.65	9.03	8.88
C 71— 96	2.33	2.15	3.90	5.38	6.00
C 71—157	2.13	1.68	1.80	100.00	100.00
C 71—171	2.15	2.15	2.65	3.98	20.80
C 71—196	2.20	1.50	1.48	90.57	100.00
Tainung 57	1.98	2.20	2.18	44.30	100.00
Average	2.25	2.00	3.05	44.77	61.55

a After being cooled from 90°C

All breeding lines had higher percentage of dry matter than Tainung 57, the highest value was 43.5 % of line C 70-220, followed by C 70-295 and C 71-96 (40.7%) (Table 4).

The average range for tuber starch content on dry basis of all sweet potatoes was between 65.83 and 69.62 %, with a difference of 3.79 %. Line C 71-94 had the widest range of 7.90 % in its starch content, followed by C 66-41 with a range of 7.15 %. The smallest difference came from line C 71-96 and was only 0.87 %. Tainung 57 had a difference of 2.93 %. Line C 71-96 had the highest starch content of 75.38 % on dry weight basis, followed by C 71-157 (71.81 %) and C 70-141 (70.02 %). All new sweet potato breeding lines were of high starchy class (Table 4).

The value of the tuber starch content on fresh weight basis could be obtained from multiplying dry matter content percentage by starch content percentage on dry basis. Line C 71-96 had the highest starch content of 30.68 % on fresh basis, while the variety Tainung 57 had the lowest starch content of 18.42 %, because its dry matter content was very low. The average wet starch content of all sweet potatoes was 24.59 % (Table 4).

Table 4. Dry matter and starch content on dry and fresh weight in sweet potatoes.

Lines & Variety	Dry matter (%)	Starch content (% d. w.)		Starch content (% f. w.)
		Range	Mean	
C 64— 4	34.0	66.27-62.63	65.39	22.23
C 64— 42	32.3	68.52-66.78	67.59	21.83
C 65—356	33.5	65.57-62.38	64.20	21.51
C 66— 33	34.5	69.26-66.37	67.74	23.37
C 66— 41	34.5	72.34-65.19	68.88	23.69
C 66— 73	32.4	68.19-65.09	67.84	21.98
C 70—111	37.6	69.70-65.23	68.38	25.71
C 70—141	39.7	71.00-68.95	70.02	27.80
C 70—220	43.5	71.95-65.43	68.09	29.62
C 70—245	37.1	71.59-66.53	68.48	25.12
C 70—295	40.7	67.50-65.31	66.26	6.97
C71 — 92	39.5	71.06-67.57	69.51	27.46
C71 — 94	36.7	70.68-62.78	68.05	24.97
C71 — 96	40.7	75.65-74.78	75.38	30.68
C71 —157	39.3	73.29-71.00	71.81	28.22
C71 —171	34.8	68.92-66.03	67.06	23.34
C71 —196	31.4	64.22-58.34	61.99	19.46
Tainung 57	27.8	67.56-64.63	66.25	18.42
Average	36.1	69.62-65.83	67.93	24.59

In regard to the reducing sugar content of dry tuber, C 71-196 had the highest value of 8.44 %, the same line had the lowest starch content on dry basis, line C 66-33 had the lowest reducing sugar of 0.24 % and Tainung 57 had a content of 3.55%. The average reducing sugar content of all sweet potatoes was 3.71 % (Table 5).

After being heated in oven at 70°C for 24 hours, the dry tubers of all sweet potatoes still had a moisture content from 7.05 % to 11.33 %, with an average of 9.52 %.

The average amylose content of all sweet potatoes was 14.25 %, which was lower than that of other starchy crops such as potato[9]. Two lines, C 66-33 and C 66-73, both

had the highest amylose content of 17.32 %, followed by C71-94 (16.70 %), while two other lines, C 70-111 and C 70-141, both had the lowest amylose quantity of only 8.50%. The variety had 13.23 % of amylose content (Table 5).

Table 5. Reducing sugar, moisture and amylose content of tuber powder in sweet potatoes.

Lines & Variety	Reducing Sugar (%)	H_2O (%)	Amylose (% d. w.)
C 64— 4	4.08	7.05	13.23
C 64— 42	1.29	8.54	15.44
C 65—356	4.97	11.03	14.80
C 66— 33	0.24	11.05	17.32
C 66— 41	2.56	10.68	16.06
C 66— 73	0.88	10.27	17.32
C 70—111	3.49	11.33	8.50
C 70—141	4.65	10.16	8.50
C 70—220	4.37	9.65	15.11
C 70—245	5.25	9.34	13.54
C 70—295	6.72	9.55	13.54
C 71— 92	3.27	6.58	16.06
C 71— 94	4.13	8.17	16.70
C 71— 96	2.74	7.28	14.49
C 71—157	3.40	8.97	14.80
C 71—171	2.70	8.50	13.85
C 71—196	8.44	9.01	13.85
Tainung 57	3.55	9.40	13.23
Average	3.71	9.52	14.25

In tuber there was more or less amylase, which could convert tuber starch into simple sugar units under normal pressure and temperature. The activity of amylase, affected by both temperature and variety, was in direct proportion to the reducing sugar content. Line C 71-196 had the highest enzyme activity with a value of 8.53. The amylase activity of the variety Tainung 57 was 3.6 units at 25°C and 4.6 units at 40°C (Table 6).

Under standard conditions (temperature 40°C, pH 5.0 and 0.56 % standard starch solution) the amylase of sweet potato tuber could easily break the α-1,4-glucosidic linkage at each possible site of starch molecule into simple sugar units, consequently the total reducing sugar content of the solution increased. The actual reducing sugar quan-

Table 6. Reducing sugar and amylase activity in sweet potato tubers.

Lines & Variety	Reducing sugar (mg/25mg tuber)		Amylase activity unit (mg reducing sugar produced/g. tuber·hr)	
	r. t. (25°C)	40°C	r. t. (25°C)	40°C
C 64— 4	1.030	1.318	4.120	5.272
C 64— 42	0.324	0.515	1.296	2.060
C 65—356	1.265	1.619	5.060	6.476
C 66— 33	0.310	0.397	1.240	1.588
C 66— 41	0.647	0.828	2.588	3.312
C 66— 73	0.221	0.329	0.884	1.316
C 70—111	0.883	1.130	3.532	4.520
C 70—141	1.180	1.295	4.720	5.180
C 70—220	1.103	1.501	4.412	6.004
C 70—245	1.325	1.428	5.300	5.712
C 70—295	1.692	2.166	6.768	8.664
C 71— 92	0.824	0.942	3.296	3.768
C 71— 94	1.045	1.162	4.180	4.648
C 71— 96	0.691	0.962	2.764	3.848
C 71—157	0.853	1.092	3.412	4.368
C 71—171	0.721	0.923	2.884	3.692
C 71—196	2.133	2.730	8.532	10.920
Tainung 57	0.897	1.148	3.588	4.592
Average	0.952	1.194	3.810	4.774

r. t. : room temperature (25°C)

tity was obtained by subtracting the increased amount from 25°C to 40°C from the total reducing sugar. From the value of actual reducing sugar content the enzyme activity of amylase in tuber under standard conditions could be calculated. Line C 71-92 had the highest amylase activity of 563.28 units, while C 70-220 the lowest of 494 units. The amylase activity of Tainung 57 was 517.6 units, lower than the average of 525.2 units (Table 7). Comparing the results of Table 6 and Table 7, a much higher reaction efficiency of tuber amylase under standard condition was found, being 110 times as high as that in tuber.

Correlation studies on these physicochemical properties of sweet potatoes showed highly significant relationships between the tuber dry matter content and starch content on fresh basis ($r=0.97$), the starch content on fresh basis and the starch content on dry basis ($r=0.77$), and the tuber reducing sugar content and the amylase activity ($r=0.98$). Significant relation also existed between the tuber dry matter content and the starch content on dry basis ($r=0.58$) (Table 8).

Table 7. Amylase activity of tuber powder in sweet potatoes under standard condition.

Lines & Variety	Reducing sugar(mg)of standard starch solution at40°C		Amylase activity unit (mg reducing sugar produced/ g. tuber·hr at 40°C)
	Total	actual	
C 64— 4	63.90	62.58	500.64
C 64— 42	66.65	66.13	529.04
C 65—356	65.00	63.38	507.04
C 66— 33	65.15	64.75	518.00
C 66— 41	66.55	65.72	525.76
C 66— 73	67.75	67.42	539.36
C 70—111	66.40	65.27	522.16
C 70—141	71.70	70.40	563.20
C 70—220	63.25	61.75	494.00
C 70—245	66.70	65.27	522.16
C 70—295	65.55	63.38	507.04
C 71— 92	71.35	70.41	562.28
C 71— 94	69.25	68.09	544.72
C 71— 96	67.45	66.49	531.92
C 71—157	68.30	67.21	537.68
C 71—171	66.70	66.78	534.24
C 71—196	64.70	61.97	495.76
Tainung 57	65.85	64.70	517.60
Average	66.84	65.65	525.20

Table 8. Correlation coefficients of the physicochemical properties of sweet potato starch.

Property	Viscosity	Dry matter	Reducing sugar	Starch (d.w.)	Starch (f.w.)	Amylose (%)	Amylase activity
Viscosity		-0.04	-0.49*	0.02	-0.03	0.38	-0.36
Dry matter	-0.04		0.15	0.58*	0.97**	-0.17	0.12
Reducing sugar	-0.49*	0.15		-0.44	-0.01	-0.39	0.98**
Starch (d.w.)	0.02	0.58*	-0.44		0.77**	-0.01	-0.50*
Starch (f.w.)	-0.03	0.97**	-0.01	0.77**		-0.14	-0.05
Amylose (%)	0.38	-0.17	-0.39	-0.01	-0.14		-0.34
Amylase activity	-0.36	0.12	0.98**	-0.50*	-0.05	-0.34	

*, **: Significant at the 0.05 and 0.01 probability levels, respectively.

From the close relationship between tuber dry matter content and starch content on wet basis, a regression equation was derived. $\hat{Y} = 0.82664\ X - 5.25795$, where $\hat{Y}$ was the tuber starch content on fresh basis and X meaned the tuber dry matter content. The slope of the regression line indicated that with every increase of 1 % of tuber dry matter, an increase of 0.83 % of tuber starch content on fresh basis was obtained (Fig. 1).

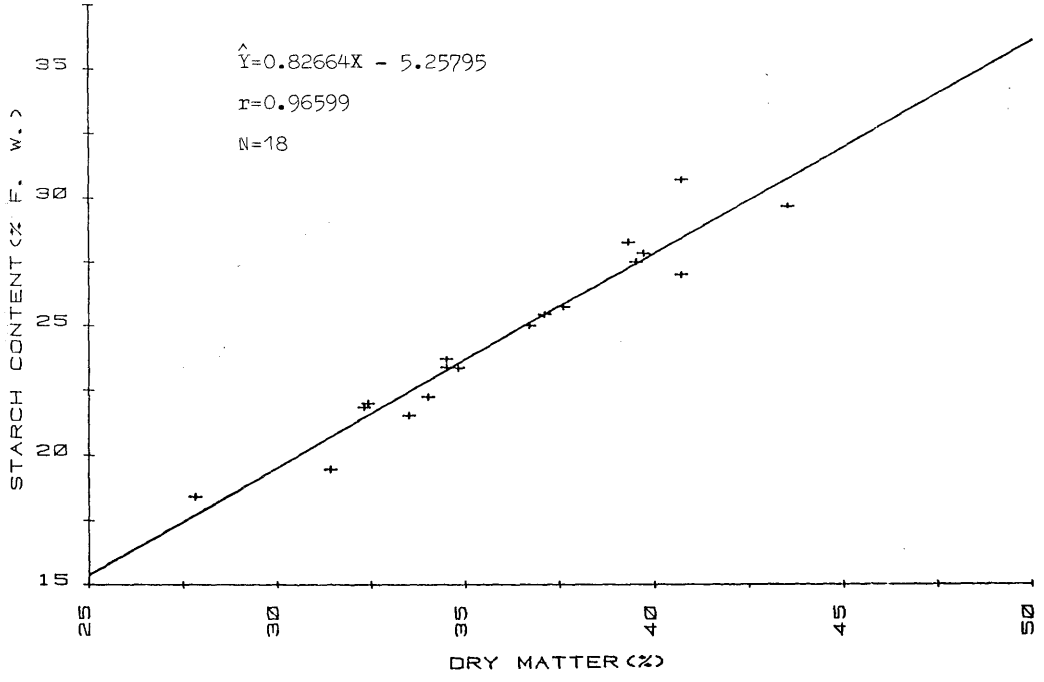

Fig. 1. Relationship between starch content ($\hat{Y}$) and dry matter (X) in sweet potatoes

Conclusion

Tuber dry matter content in sweet potatoes was found to have a closer relationship with starch content on fresh basis than that on dry basis. The result of the present study showed that every increase of 1 % of tuber dry matter content would give an increase of 0.83 % of tuber starch content on fresh basis. Li and Liao[7] (1983) also indicated that 0.63 % of crude starch content could be expected from each percent of tuber dry matter. The development of sweet potato varieties with high tuber dry matter content through breeding should be therefore emphasized.

The average starch content on dry basis of all sweet potatoes was very high with a value of 67.93 %, being higher than that of other starchy crops in Taiwan such as cassava (58.1 %), arrowroot (64.0 %), yam (66.7 %) and edible canna (65.3 %)[8]. In addition to the high starch content sweet potato is a high yielding crop with three or four crops a year locally[10] and can produce a high starch yield.

The starch quality is related with the factors like flavour, viscosity, colour and starch

content. Good quality requires good flavour, high and stable viscosity, white colour and high starch content. After assessment with these factors the following lines were selected to be of better quality in their starch: C 64-4, C 64-42, C 65-356, C 66-33, C 66-41, C 70-295 and C 71-157.

Considering the world's reserves and the annual consumption and the still increasing rate of consumption, the possible providing years of the following fossil fuels were estimated to be 30 years in oil, 50 years in gas, 76 years in uranium and 300 years in coal[10]. Because of the limited supply of fossil fuels and other possible difficulties like political, technical and secure problems all nations in the world have been trying to explore possible energy resources. Alcohol, one of the many found substitute energy resources, is specially attractive because it can be easily produced by starchy or sugary biomass[9,11]. All sweet potatoes tested in this study are rich in starch content, hence, on the one side they can provide a high starch yield, on the other side they can also be used as materials for producing alcohol.

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甘藷新品系塊根理化性質之研究[1]

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摘 要

本研究在分析甘藷17個新品系及臺農57號塊根之理化性質，藉以評估其品質之優劣及探討甘藷塊根之乾物率、澱粉率，還原糖含量與澱粉水解酵素之活性間的相互關係。

在物理性質方面，這18個甘藷品系（種）的澱粉粒大小介於 28.98×26.57μ 及8.05×7.25μ之間。所有甘藷澱粉溶液於溫度上升到 90°C 時之粘度約爲最初室溫的20倍。由90°C冷却回室溫時，其粘度呈繼續上升趨勢，只有C70-111及C71-94二品系的粘度略呈下降現象。有三個新品系之塊根乾物率超過40%，而所有甘藷新品系之平均乾物率高達36.6%，且都比臺農57號的27.8%爲高。塊根之含水率則以臺農57號最高（72.2%），超出含水率之平均值達8.3%。

在化學性質方面，參試甘藷烘乾塊根之澱粉率的變域在61.99%及75.38%之間，此表示因品種之不同將有很大的差異。在17個新品系中有 53%新品系之澱粉含量超過平均值（67.93%），即使最低的品系也含有 61.99 %的澱粉率，所以這些甘藷應歸屬於高澱粉之甘藷品系。塊根鮮重澱粉率之變域在18.42—30.68%之間。由於臺農57號之乾物率最低，此將明顯不利於鮮重澱粉率，其鮮重澱粉率爲所有參試甘藷中最低者（18.42%），而 C71-96則同時具有最高的鮮重及乾重澱粉率。在澱粉之化學結構中，顆粒澱粉之平均含量爲14.25%，其變域在8.50到17.32%之間。而烘乾塊根之平均還原醣含量爲3.71%，最高值達8.44%，最低的只有0.24%，此顯示在塊根中存在著或多或少的澱粉水解酵素，於常溫常壓下能分解塊根澱粉成爲還原醣。

在所有塊根之理化性質中，有下列三項性質呈現極顯著關係：塊根乾物率與鮮重塊根澱粉率（r=0.96599），鮮重澱粉率與乾重澱粉率（r=0.76782）以及還原醣含量與澱粉水解酵素之活性（r=0.98117）。由於塊根乾物率與塊根鮮重澱粉率之關係爲爲密切，所以可由甘藷塊根乾物率來估算求得塊根鮮重澱粉率。兩者之直線迴歸方程式爲：$\hat{Y}=0.82664X-5.25795$, $\hat{Y}$ 爲塊根鮮重澱粉率，X爲塊根乾物率，式中表示每提高塊根乾物率1%，即可能增加其塊根鮮重澱粉率0.83%。此應可利用爲高澱粉甘藷育種工作之一種指標。

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